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THE EFFECTS OF BEHAVIORAL HISTORY ON RESPONSE ACQUISITION WITH IMMEDIATE AND DELAYED REINFORCEMENT

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Effects of prior exposure to the experimental chamber with levers present or absent and variable-time (VT) 60-s water deliveries arranged during one, five, or no 1-hr sessions were examined in rats during a 6-hr response-acquisition session in which presses on one lever produced water delivery immediately or after a 15-s resetting delay, and presses on the other lever canceled scheduled water deliveries. Response acquisition was (a) slower to occur when water deliveries were delayed, (b) most consistent in groups that had received five VT sessions, and (c) impaired by the presence of levers only when there had been five VT sessions and water deliveries were delayed during the acquisition session.

Key words: response acquisition, delayed reinforcement, magazine training, behavioral history, operant conditioning, lever-press, rats

In 1990 Lattal and Gleeson demonstrated that, in the absence of shaping or autoshaping, rats and pigeons could learn to bar press or key peck, respectively, when food deliveries were delayed by up to 30 s relative to the response that produced them (Lattal & Gleeson, 1990). Since this seminal work appeared, several other studies have demonstrated response acquisition with delayed reinforcement (e.g., Critchfield & Lattal, 1993; Dickinson, Watt, & Griffiths, 1992; Lattal & Metzger, 1994; van Haaren, 1992; Wilkenfield, Nickel, Blakely, & Poling, 1992). Poling and his associates have suggested that response acquisition procedures with delayed reinforcement may be especially sensitive and valuable assays of drug effects (Snycerski, Laraway, Byrne, & Poling, 1998), and they (Byrne, Baker, & Poling, 2000; Byrne, LeSage, & Poling, 1997; LeSage, Byrne, & Poling, 1996) and others (van Haaren, 1992) have examined the effects of several drugs under such procedures. A problem in these studies, however, was the substantial variability across subjects exposed to the same experimental conditions. If response-acquisition procedures are to be useful as baselines for studying the effects of drugs or other independent variables, such as genotype (e.g., Baron & Meltzer, 2001), then it is necessary to isolate and eliminate extraneous sources of variability. Isolating the variables that influence response acquisition with delayed reinforcement also is necessary to understand the phenomenon.

Magazine training procedures implemented prior to response acquisition sessions may be one potential source of variability. In the drug studies mentioned above, rats were exposed to a single 1-hr session of response-independent (variable-time [VT] 1 min) deliveries of the putative reinforcer prior to a single response-acquisition session. The purpose of the former session, like that of all magazine training sessions, was (a) to establish the sound of food or water delivery as a conditioned reinforcer and (b) to establish a stable chain of responses (staying near the source of food or water delivery, approaching food or water rapidly when they are presented) that is subsequently extended to include lever pressing (Kelleher & Gollub, 1962; Sidman, 1960; Skinner, 1938). No formal attempt was made, however, to determine whether the VT session accomplished these functions. Although Lattal and Williams (1997, Experiment 3) demonstrated that magazine training is not necessary for establishing new behavior with delayed reinforcement, no one has systematically compared the effects of different magazine-training procedures on response acquisition. One purpose of the present study was to examine the effects of different magazine training conditions on response acquisition. In this study, some rats received no exposure to the experimental chamber prior to the response-acqui-

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sition session whereas others were given 1 hr of exposure to the chamber without water deliveries. Other rats received either one or five 1-hr sessions of exposure to the chamber with a VT 60-s schedule of water delivery in effect.

In some studies of lever-press acquisition by rats (e.g., Byrne et al., 1997; Sutphin, Byrne, & Poling, 1998; Wilkenfield et al., 1992) but not others (e.g., Lattal & Gleeson, 1990; Stolerman, 1971a, 1971b; van Haaren, 1992), levers were removed from the chamber during magazine training sessions. The purpose of removing the levers in the former studies was to eliminate the possibility of adventitious reinforcement of lever pressing by response-independent deliveries of the stimulus subsequently to be used as a response-dependent reinforcer. The effects, if any, of this manipulation, however, have not been determined, and it is not clear whether removing the levers influences between-subject variability. A second purpose of the present study, therefore, was to compare response acquisition with delayed and immediate reinforcement in groups of rats for which levers were and were not retracted during magazine training. The variables of interest were examined under conditions of immediate and delayed reinforcement because previous studies have demonstrated that the effects of some independent variables (e.g., drugs; Byrne et al., 1997, 2000; Laraway, 2003) differ under these conditions.

METHOD

Subjects

Experimentally naive male Sprague Dawley rats, obtained from Charles River (Portage, MI) and between 50 and 53 days old at the beginning of the experiment, served as subjects ($N = 240$). Rats were water deprived for 22.5 hr prior to each session and were given free access to water for 30 min after each session. Rats were housed in pairs with unlimited access to food in a colony area with a 12:12 hr light/dark cycle (lights on at 7:00 a.m.).

Apparatus

Eight Med Associates (St. Albans, VT) operant test chambers were used. The chambers were 28 cm long by 21 cm wide by 21 cm high. Two retractable response levers separated by 8.5 cm were mounted on the front panel 7 cm above the chamber floor. A minimum force of 0.14 N was required to operate the levers. A receptacle located in the center of the front panel 3 cm above the chamber floor allowed access to a dipper cup filled with 0.1 ml of tap water. A 7-W white bulb located on the ceiling illuminated the operant chamber. An exhaust fan in each chamber masked extraneous noise and provided ventilation. An IBM®-compatible microcomputer equipped with MED-PC® software controlled experimental events and recorded data.

Procedure

Figure 1 depicts the historical and experimental conditions for all groups of rats and lists the groups' names that will be used throughout the remainder of this report. Rats were randomly assigned to 1 of 15 groups of 16 rats each.

Historical conditions. Three groups of rats did not receive exposure to the experimental chamber prior to the response acquisition session. Four groups of rats received one 1-hr exposure to the experimental chamber. For two of these groups response levers were present in the chamber, and for the other two groups response levers were retracted, leaving a smooth wall. Four more groups of rats received one VT exposure session, and for two of these groups response levers were present and for the other two groups the response levers were retracted. Another four groups of rats received five 1-hr VT exposure sessions, and for two of these groups the response levers were present and for the other two groups the response levers were retracted. For rats receiving VT exposure, a VT 60-s schedule of water delivery was arranged. Under this schedule, 4-s dipper presentations occurred on average every 60 s, regardless of the rat's behavior. The progression of interstimulus intervals of the VT schedule was derived using the algorithm described by Fleshler and Hoffman (1962). VT exposure sessions were 1 hr in duration. For groups with levers present during VT exposure sessions, presses on both levers were recorded but had no programmed consequences.

Response-acquisition conditions. All groups of rats from each of the seven historical conditions were exposed to a resetting/cancellation response-acquisition procedure with ei-

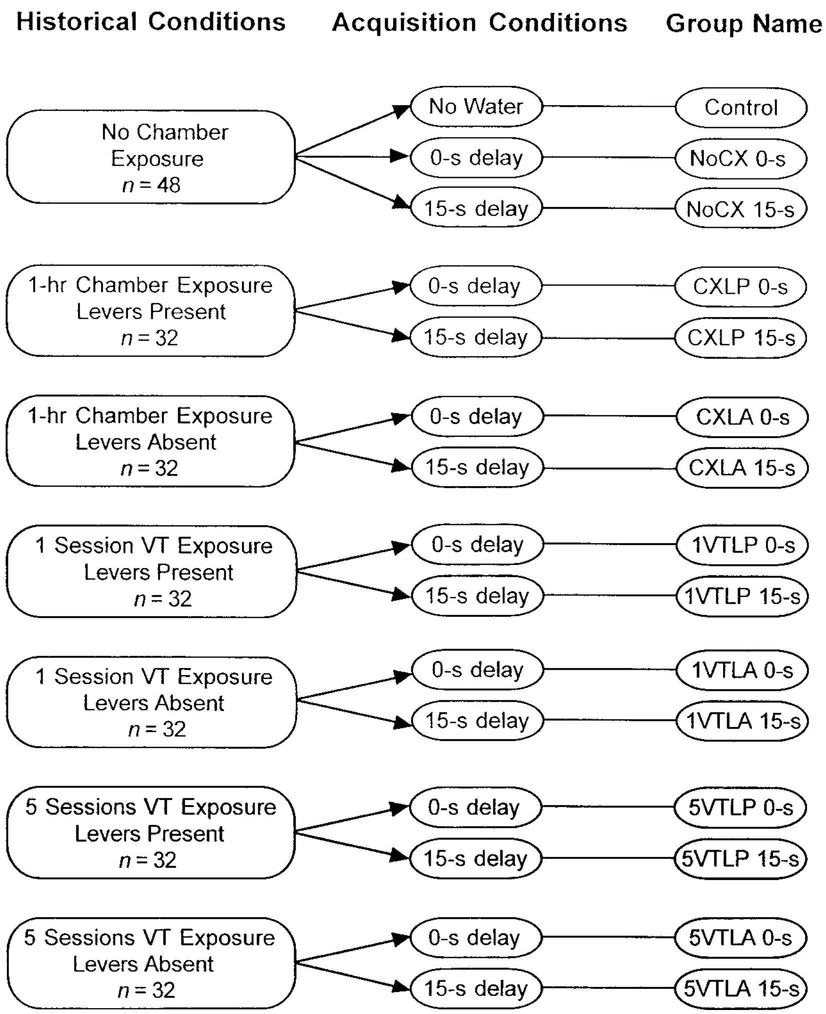

Fig. 1. Historical and acquisition conditions for all groups of rats and the group names.

ther immediate reinforcement (0-s delay) or delayed reinforcement (15-s delay). Two response levers were present during these sessions and the location of the reinforcement and cancellation levers was determined at random. Response-acquisition sessions lasted for 6 hr. For all groups, the white bulb located in the ceiling of the chamber was lighted when the response-acquisition session began and darkened when it ended. Reinforcement-lever responses produced 4-s access to a dipper cup filled with 0.1 ml tap water for all experimental groups. For the control group, reinforcement-lever responses produced 4-s access to an empty dipper cup (i.e., no water) and cancellation lever responses had no programmed consequences.

Seven of the 15 groups of rats were exposed to an immediate reinforcement condition in which responses on the reinforcement lever immediately produced dipper access. For these groups, responses on the cancellation lever had no programmed consequences and responses on both levers were recorded. Another seven groups of rats were exposed to a delayed reinforcement condition (i.e., a tandem fixed-ratio 1 not-responding-greater-than-15-s schedule) in which responses on the reinforcement lever produced dipper access after 15 s had elapsed. Responses on the reinforcement lever that occurred during a delay interval reset the interval to the initial value (i.e., an unsignaled resetting delay was arranged). Responses on the cancellation lever that occurred during a delay interval canceled the scheduled water delivery and terminated the delay, in which case another reinforcement-lever response was necessary to start a new delay interval. Responses on the cancellation lever at other times had no programmed consequences.

Dependent measures. During response-acquisition sessions, the following dependent measures were collected in 10-min bins: (a) number of responses on the reinforcement lever (i.e., *R-L responses*), (b) number of responses on the cancellation lever (i.e., *C-L responses*), (c) number of reinforcement-lever responses that reset the delay interval (i.e., *Resets*), (d) number of cancellation-lever responses that canceled scheduled water deliveries (i.e., *Cancels*), and (e) number of dipper presentations. Total lever presses during VT sessions also were recorded for relevant groups.

RESULTS

Effects of VT Water Deliveries on Lever Pressing

Figure 2 shows, for relevant groups, the mean number of responses on each lever during VT and response-acquisition sessions. These data indicate that VT water deliveries engendered relatively little responding on either lever and no consistent difference in responding on the two levers. Responding increased dramatically on the reinforcement lever during the response-acquisition session. Responding on the cancellation lever also increased, but substantial differences in responding on the two levers were apparent in each of the four relevant groups.

Response Acquisition Defined

A rat was considered to have acquired the lever-press response if, by the end of the 6-hr session, it made at least 12 R-L responses and more R-L responses than C-L responses. The value of 12 R-L responses represents one response more than the upper limit of the 99% confidence interval around the mean number of R-L responses (that resulted in presentation of the empty dipper) made by rats in the control group ($M = 7$, upper limit = 11).

Effects of Behavioral History on Response Acquisition

Table 1 provides summary descriptive statistics for all groups during the 6-hr response-acquisition session. Figures 3 and 4 show individual and group mean cumulative R-L responses during the response-acquisition session for all groups exposed to immediate and delayed reinforcement, respectively. For each condition, the number of rats that met the acquisition criterion is provided. The cumulative record from the Control group represents the *operant level* of responding in the absence of programmed reinforcement contingencies. As shown in Figure 3, the number of rats that met the acquisition criterion systematically increased as a function of their behavioral histories. Groups that received VT exposure had more rats that acquired the R-L response than groups that did not receive VT exposure. Moreover, groups given five VT sessions had more rats acquire the R-L response than groups given one VT session. In general, within-group variability in cumulative records systematically decreased as the number of VT sessions increased. For groups exposed to immediate reinforcement, a history of exposure to the response levers did not appear to affect response acquisition. The effects of experimental manipulations on the mean number of water deliveries (Table 1) were similar to the effects on R-L responding; therefore, the former measure will not be discussed separately.

Figure 4 presents the cumulative records of individual rats exposed to a 15-s delay during the response-acquisition session. As in previous studies, delayed reinforcement slowed the development of responding, as evidenced by relatively flat cumulative records. In addition, repeated exposure to VT sessions with the response levers present affected subsequent performance during the response acquisition session. In the 5VTLA 15-s group, 14 of 16 rats acquired the lever-press response, whereas only 7 of 16 rats did so in the 5VTLP 15-s group. Hence, for rats that received five VT sessions, the presence of response levers during those sessions impaired performance during the acquisition session.

Figure 5 shows group mean cumulative records for R-L and C-L responses during the acquisition session for groups exposed to immediate reinforcement. For all of these groups, the mean number of R-L responses was greater than the mean number of C-L responses. Nevertheless, the time at which the R-L and C-L curves begin to separate varied

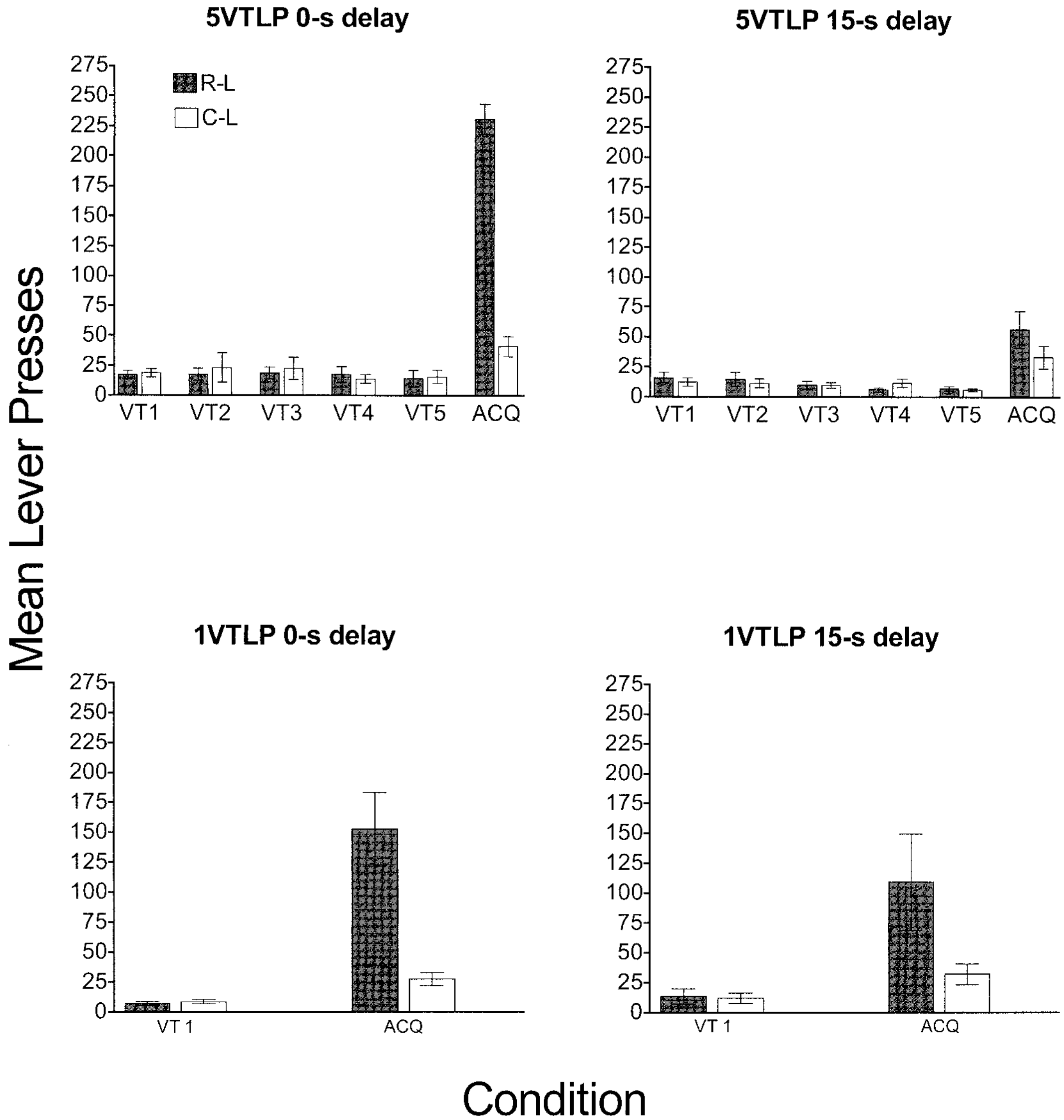

Fig. 2. Mean (± *1 SEM*) number of responses on each lever during the 1-hr VT sessions and the 6-hr response-acquisition sessions for all groups receiving VT exposure.

across groups. The point of separation of these two curves indicates when the consequences arranged on the R-L lever began to control responding on this lever. The point of separation occurred earliest in the session for groups that received five VT exposures, and these groups made most of their responses within the first 50 min of the session.

Figure 6 shows group mean cumulative records for all groups exposed to delayed reinforcement. Rats in all these groups except one (the CXLA 15-s group) made more R-L responses than C-L responses. For all delayed reinforcement groups, resets accounted for approximately half of all R-L responses. Few Cancels occurred in any group. The group cumulative records for the two groups that received five VT sessions show striking differences with respect to the absolute number of R-L responses and to the relative number of R-L to C-L responses. Unlike the immediate reinforcement groups, the presence of the levers during the five VT sessions substantially attenuated acquisition of lever pressing (com-

Table 1

Descriptive statistics for all groups during the 6-hr response-acquisition session.

Group	Reinforcement-lever responses		Cancellation-lever responses		Resets		Cancels		Dipper presentations	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	7	5	9	9	—	—	—	—	7	5
NoCX 0-s	38	69	14	16	—	—	—	—	38	69
NoCX 15-s	18	14	12	11	8	7	1	2	10	6
CXLP 0-s	78	112	18	20	—	—	—	—	78	112
CXLP 15-s	39	57	16	12	17	29	2	3	21	28
CXLA 0-s	77	114	45	104	—	—	—	—	77	114
CXLA 15-s	34	62	35	63	14	25	2	5	18	33
IVTLP 0-s	152	122	27	21	—	—	—	—	152	122
IVTLP 15-s	109	162	32	35	54	102	2	3	53	62
IVTLA 0-s	112	99	37	36	—	—	—	—	112	99
IVTLA 15-s	87	79	60	56	32	29	5	8	50	50
5VTLP 0-s	231	50	41	33	—	—	—	—	231	50
5VTLP 15-s	56	62	33	38	16	19	2	2	38	44
5VTLA 0-s	204	72	48	32	—	—	—	—	204	72
5VTLA 15-s	156	69	69	59	62	36	7	8	87	38

pare the bottom left panels of Figures 5 and 6).

To examine the effects of behavioral history on response efficiency, the mean ratio of C-L to R-L responses during the response-acquisition session was calculated for each group. These proportions are presented in Figure 7. A value of 1.0 indicates equal responding on both levers or lack of differential control by either lever. Values above 1.0 indicate more responding on the cancellation lever, whereas values below 1.0 indicate more responding on the reinforcement lever. As this figure shows, all but one group (CXLA 15-s) made more responses on the reinforcement lever. For most groups, the ratio of responding on the cancellation lever decreased and then reached an asymptote before the end of the session. In general, groups that received immediate reinforcement reached asymptotic levels of responding much earlier in the session than did groups that received delayed reinforcement.

DISCUSSION

Prior findings indicate that response-independent deliveries of food or water, presented when they are earned by other rats in a yoked-control arrangement, do not generate substantial levels of lever-pressing in the yoked rats (Lattal & Gleeson, 1990; LeSage et al., 1996). The present findings demonstrate that purely time-based water deliveries, arranged under a VT 60-s schedule, resulted in levels of responding similar to those observed in a control group of rats that never received water. Under conditions of response-dependent water delivery, there was an orderly relation between type of behavioral history and levels of responding on the R-L and C-L levers. The simplest behavioral history consisted of merely keeping rats in their home cages until they were placed in the experimental chamber for the acquisition session. Few rats given this type of history acquired the operant response. Similarly, few rats given a history of exposure to the experimental chamber met the two-part criterion for acquisition. The finding that some rats in these conditions acquired the operant response in the absence of any kind of magazine training confirms the finding by Lattal and Williams (1997, Experiment 3) that magazine training is not necessary for acquisition to occur. Nevertheless, providing rats with a history of magazine training (in this case, exposure to a VT 60-s schedule) resulted in more consistent acquisition, as evidenced by increases in the number of rats that met the criterion for response acquisition and in the number of R-L responses made by these rats.

The most consistent response acquisition was evident in the groups that received five sessions of VT exposure. Of the groups that received five VT sessions, three of four

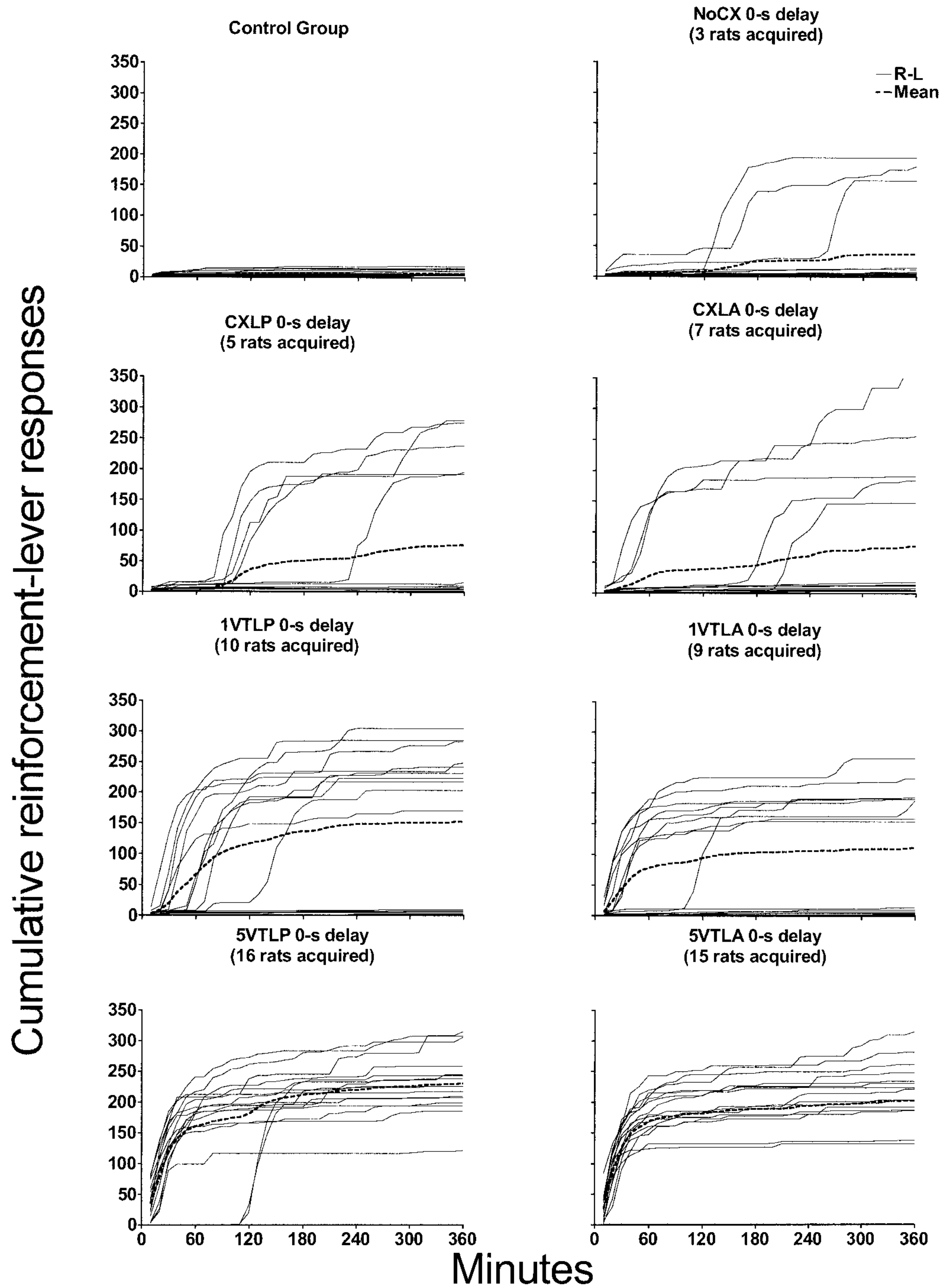

Fig. 3. Individual and group mean cumulative records of reinforcement-lever (R-L) responding occurring in 10-min bins during response-acquisition sessions for all groups of rats exposed to immediate reinforcement. Cumulative records for the control group are also depicted. Rat 7 in the CXLA 0-s delay group made a total of 364 responses.

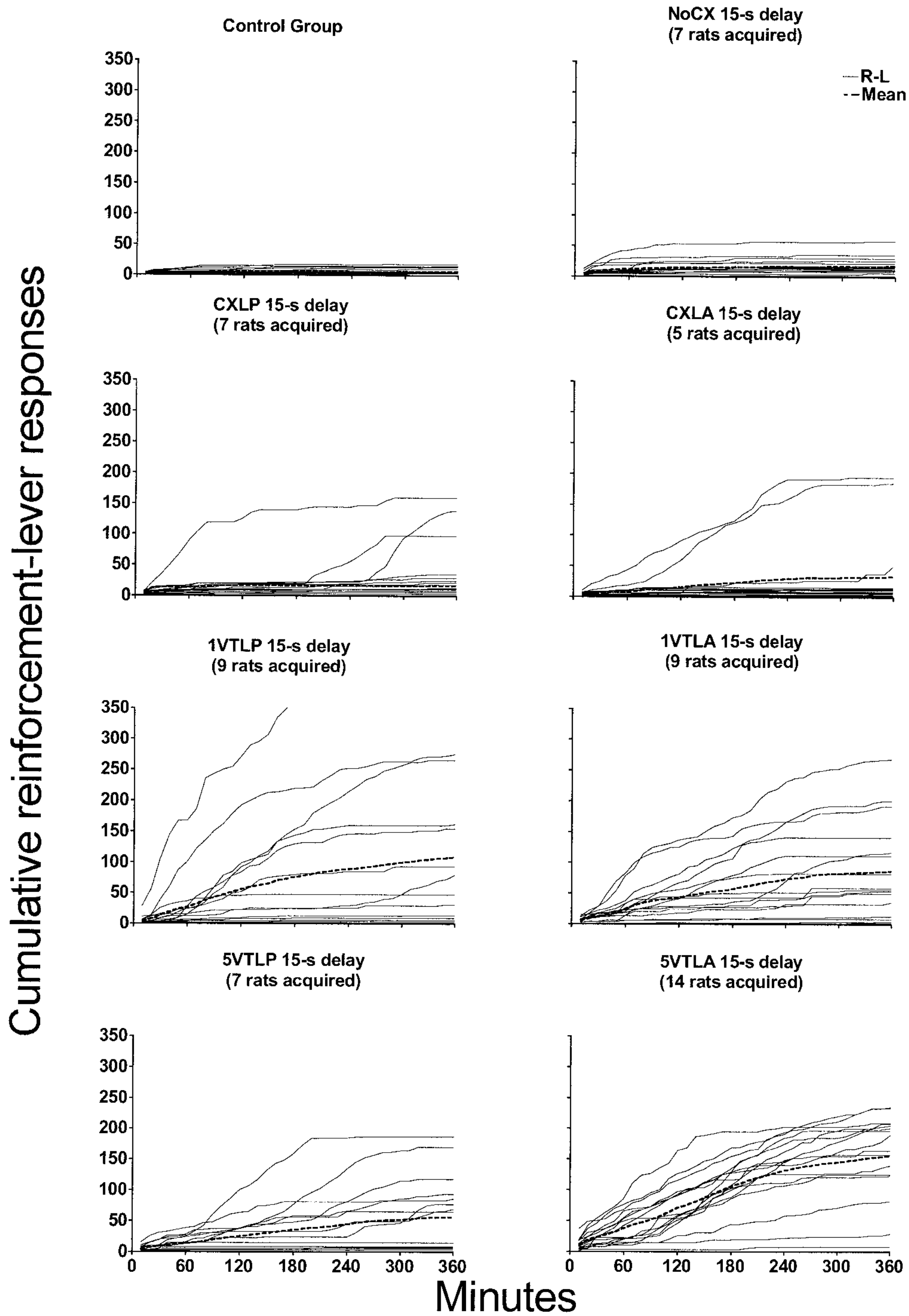

Fig. 4. Individual and group mean cumulative records for reinforcement-lever (R-L) responses occurring in 10-min bins during response-acquisition sessions for all groups of rats exposed to a 15-s resetting delay. Cumulative records for the control group are also depicted. Rat 15 in the 1VTLP 15-s delay group made a total of 607 responses.

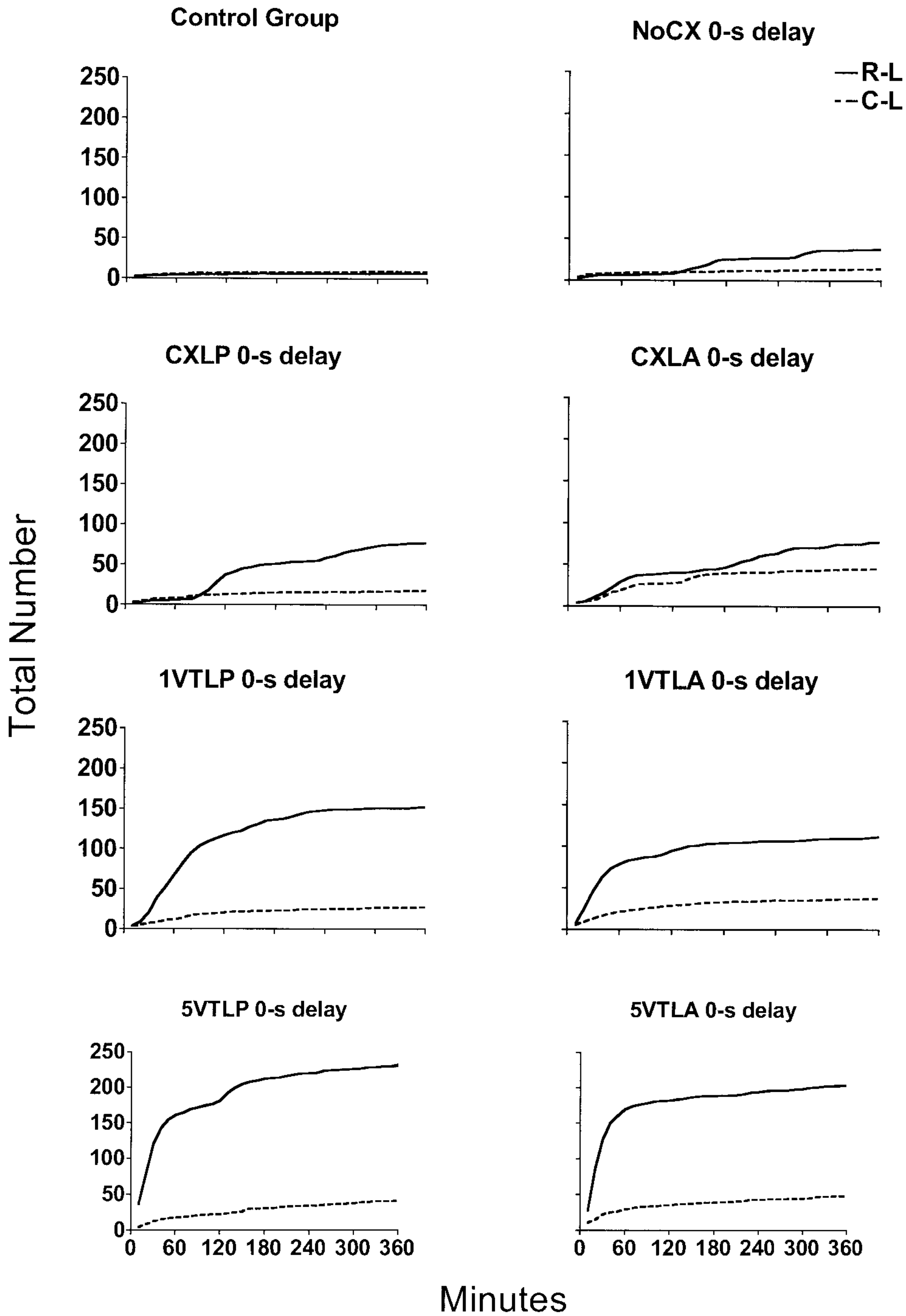

Fig. 5. Group mean cumulative records for reinforcement- and cancellation-lever (R-L and C-L, respectively) responses occurring in 10-min bins during response-acquisition sessions for all groups exposed to immediate reinforcement. A group mean cumulative record for the control group is also depicted.

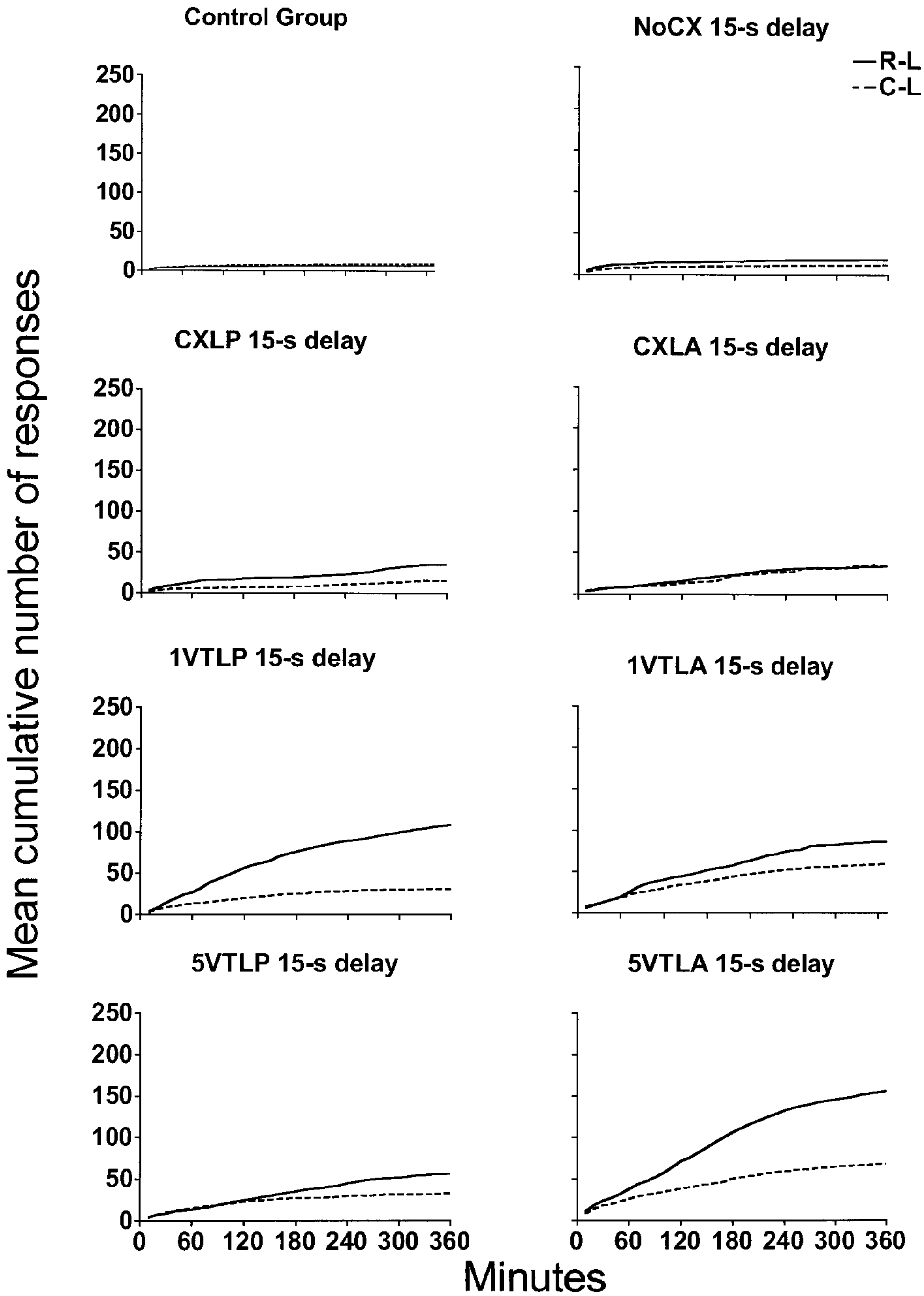

Fig. 6. Group mean cumulative records for reinforcement- and cancellation-lever (R-L and C-L, respectively) responses occurring in 10-min bins during response-acquisition sessions for all groups exposed to 15-s resetting delay conditions. A group mean cumulative record for the control group is also depicted.

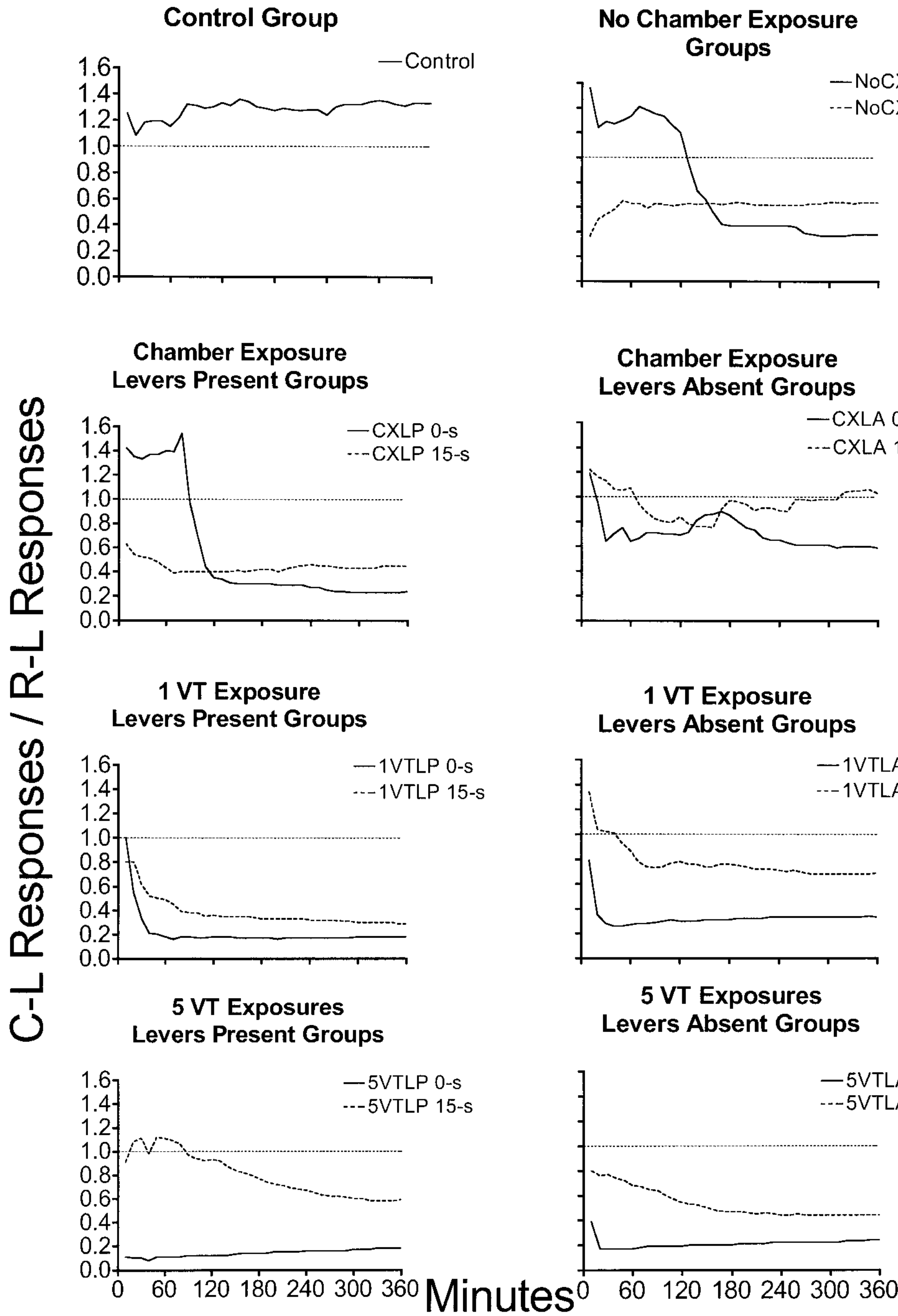

Fig. 7. Ratio of cancellation-lever to reinforcement-lever responses in 10-min bins for all groups.

groups had more R-L responses and more rats that acquired the response than the groups that received only one VT session. Indeed, the 5VTLP 0-s group was the only group in which all 16 rats acquired the lever-press response. In the 5VTLA 0-s group, 15 of 16 rats met the acquisition criterion. Rats in both of these groups showed similar patterns of responding across the session that can be characterized by a monotonically increasing curve. A probable reason for the consistency of acquisition with five VT sessions is that multiple VT sessions increased rats' opportunity to contact the water dipper, thereby increasing the likelihood that appropriate behavior with respect to the dipper would be established (i.e., approaching the dipper when it is raised and staying near the source of reinforcer delivery). It is possible, of course, that multiple VT sessions are not required for consistent acquisition. A single, lengthy VT session might also lead to consistent acquisition of the target operant. Be that as it may, the present data emphasize the importance of ensuring that subjects receive adequate magazine training.

The presence of the levers in the experimental chamber during chamber exposure and VT exposure sessions had inconsistent effects across groups. When reinforcement was immediate, the prior presence of the response levers did not appear to affect the number of rats that acquired the response, but the groups with levers present typically had a higher mean number of R-L responses that might be construed as evidence for better learning. These data are consistent with those reported by Stolerman (1971a), who found a high correlation (i.e., 0.70) between the number of lever presses made by rats during magazine training sessions and the number of responses those rats made during subsequent acquisition sessions. When reinforcement was delayed, however, the effects of the presence of response levers depended on the number of VT sessions. For the groups that received only one VT session, the presence of the levers resulted in a higher mean number of R-L responses but had no effect on the number of rats that acquired the response. For the groups that received five VT sessions and delayed reinforcement, the presence of the levers appeared to reduce both the number of rats that acquired the response and the mean number of R-L responses (see Figures 4 and 6).

A possible explanation for the inconsistent acquisition observed in the 5VTLP 15-s group is that the response-independent delivery of the putative reinforcer during VT sessions resulted in what has been termed *learned laziness* (Enberg, Hansen, Welker, & Thomas, 1972). Enberg et al. suggested that when response-independent deliveries of food or water are arranged, organisms learn not to respond on available operanda because such responses do not produce food or water. Although researchers have demonstrated that prior exposure to response-independent deliveries of a reinforcer sometimes interfere with the subsequent development of a new behavior such as key pecking in pigeons (Schwartz, Reisberg, & Vollmecke, 1974) or lever pressing in rats (Wheatley, Welker, & Miles, 1977), the use of the learned laziness concept to explain this phenomenon has been criticized for several reasons (see Gamzu, Williams, & Schwartz, 1973). In any case, our results provide no consistent evidence that response-independent water delivery impairs subsequent response acquisition. Similar results were reported previously by Stolerman (1971a, 1971b) and Lattal and Gleeson (1990).

The present findings, like those of Lattal and Williams (1997), suggest that exposure to magazine-training procedures (VT exposure in the present case) is necessary to produce consistent response acquisition, as defined by similar patterns of responding and most subjects meeting a reasonable acquisition criterion. The absolute number of VT exposure sessions required to produce the most consistent and reliable acquisition was not determined in the present study, but its results suggest that this value would not exceed five 1-hr exposures to a VT schedule.

Results from the present study indicate that, when magazine training procedures are sufficient, the resetting/cancellation procedure generates consistent response acquisition, making this procedure useful for rapidly examining the effects of various independent variables on the initial acquisition of a novel response. Variations of this procedure also could be used to examine the behavioral processes involved in the transition from operant-level responding to steady-state responding that we term *response acquisition.* For instance, an interesting aspect of the present data is that all of the reinforcement-delay groups emitted a substantial number of C-L responses during the response-acquisition session, even though the time elapsed from the emission of such responses to water delivery was never less than 15 s. We made no attempt to determine the variables responsible for the increase in C-L responding that occurred during the response-acquisition session, but obvious possibilities are response chaining (i.e., C-L responses preceded R-L responses and subsequent water deliveries, which reinforced both responses), increases in motor activity due to water delivery, and response induction (e.g., proprioceptive and exteroceptive stimuli produced by responses on both levers serve as conditioned reinforcers because, when produced by R-L responses, they are reliably followed by water delivery). The two former possibilities could be evaluated by examining videotapes of rats, the latter by comparing responses that are and are not topographically similar (cf. Critchfield & Lattal, 1993; Schlinger & Blakely, 1994).

Regardless of the variables responsible for the increase in C-L responding observed during response acquisition sessions in the present study, the finding that more R-L than C-L responding occurred, coupled with the finding that substantially more R-L responding occurred in experimental than in control rats, appears to provide compelling evidence of sensitivity to programmed contingencies, which is the quintessence of operant response acquisition. As Sidman (1960) noted, transition states are important behavioral phenomena in their own right (p. 263) and deserve intensive study, but such study demands a sufficiently powerful experimental methodology (p. 289). The present findings, like those of prior investigations (e.g., Snycerski, Laraway, Byrne, & Poling, 1999; Sutphin et al., 1998), make it clear that procedural details and the measures used to define and index behavior can substantially influence the results of studies of response acquisition. Although it is naive to assume that there is one best way to study response acquisition, it is equally naive to assume that all experimental strategies are equivalent.

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